LASER-EXCITED X-RAY SOURCE

This application claims benefit of international application PCT/GB94/00928, filed Apr. 29, 1994, published as WO94/26080 Nov. 10, 1994.

FIELD OF THE INVENTION

This invention relates to laser-excited X-ray sources and, in particular, to a laser-plasma X-ray source having a target which is irradiated by the output of a suitable laser, preferably an excimer laser.

BACKGROUND OF RELATED ART

Such X-ray sources have been employed in applications such as X-ray spectroscopy, X-ray lithography, radiobiology and X-ray microscopy, and an X-ray source of this kind has been described in considerable detail in a paper entitled "100 Hz KrF Laser-Plasma X-ray Source" presented at a conference entitled "Excimer Lasers and Applications III" at The Hague, Netherlands in 1991 and published in the Proceedings of SPIE—The International Society for Optical Engineering (SPIE Vol. 1503 Excimer Lasers and Applications III (1991), 391–405). As there described, an X-ray source comprises an excimer laser system which generates UV light pulses, at a repetition rate up to 100 Hz, which are focused on to an X-ray target. The target consists of a tape of suitable material, such as copper, steel or mylar, chosen in dependence on the desired frequency of the X-rays to be generated, and a tape transport mechanism which moves the tape so that each light pulse impinges on a fresh part of the tape, undamaged by previous pulses. Each light pulse, impinging on the tape, generates at the tape surface a highly localized volume of plasma which emits the desired X-rays but also has the effect of attenuating the UV light and shielding the tape from it, and thereby limiting the duration of the period in which X-rays are emitted. The incident UV light also causes debris to be ejected from the tape, and the debris tends to settle on surfaces of the optical system which delivers the UV light pulses to the tape and thus reduce the intensity of the incident light. As described in the above-mentioned paper, attempts to minimize these shielding effects include arranging a flow of helium gas across the part of the tape surface on which the UV light is incident, so as to sweep away and remove the debris, and assist in dissipating the plasma rapidly at the end of a pulse, and also to operate the system with the target not under highly reduced pressure but in a helium atmosphere at or approaching atmospheric pressure, which does not affect the emission of X-rays but has the effect of stopping and removing fast ions emitted by the plasma. In spite of such measures, however, it is found that in use of the known apparatus referred to the X-ray pulse generated by a pulse of UV light lasting 20 or 30 nanoseconds is generally limited to a duration of not more than 5 nanoseconds.

This shielding of the target from the incident UV laser light, in the known X-ray source referred to above, and heat loss from the expanding plasma, represent a severe limitation of the "conversion efficiency" (i.e. the ratio of X-ray energy to laser energy) of the apparatus, and a corresponding limitation on its average X-ray output power. These are factors which greatly affect the suitability of such apparatus for use in, particularly, X-ray lithographic work, for example in microcircuit production, where the highest possible average X-ray powers are required in order to minimize processing times.

It has been proposed (App. Phys. Lett. 55 (25), December 1989 and 71 (1), January 1992) to reduce the shielding effect, and improve the conversion efficiency and the average X-ray output power in such apparatus, by arranging that the laser light is emitted not in individual pulses with a pulse duration measured in tens of nanoseconds but in trains of ten to fifteen substantially shorter pulses, each pulse having a duration of about 0.10–0.15 nanoseconds, with the overall duration of the pulse train being about 20 to 30 ns. This proposal enables the conversion efficiency and average X-ray output power, when comparing a pulse train of 20 or 30 ns duration with a single pulse of equal length, to be increased significantly, by a factor of about three; but further improvements in these respects is required to make apparatus of this kind practical and competitive, and it is an object of this invention to provide such further improvements in a substantial degree.

SUMMARY OF THE INVENTION

The invention is based on the discovery that a substantial and surprising further increase in conversion efficiency and average X-ray output power can be achieved by employing a laser light source which generates trains of pulses in which the individual pulses have a much reduced duration, being in the range 1–10 ps instead of the 0.10–0.15 nanosecond pulse duration suggested as noted above. The resulting improvement, even before advantage is taken of other novel features incorporated into preferred embodiments, may amount to a further increase by a whole order of magnitude in the conversion efficiency and in the average X-ray output power.

According to the invention, therefore, there is provided an X-ray source comprising a target, a laser light source and means for focussing light from the light source on to the target, thereby to heat a region of the target and generate therefrom a plasma adjacent thereto which emits X-rays, wherein the laser light source is designed to generate trains of light pulses each having a pulse duration in the range 1–10 picoseconds.

Preferably, the laser light source is designed to generate trains of pulses of ultraviolet light; and also, preferably, it is designed to have an output power such that the light from it, focussed on the target, will illuminate the region of the target with an irradiance sufficient to generate X-rays at a wavelength equal to or less than one nanometer. Preferably, also, the laser light source is designed to generate trains of pulses with a pulse repetition time in the range 1.5–2.5 nanoseconds, and with a pulse train repetition rate in the range 100–10000 Hz, as appropriate to the lasers employed. The target, preferably, comprises a band or tape of target material, guide means supporting a part of the band or tape which includes the region of the target, and transport means arranged to move the tape over the support means; and preferably the guide means is apertured, behind the region of the target, to allow the escape through the guide means of target debris produced on perforation of the target by laser light focussed thereon.

In known manner, the target will normally be housed within a chamber containing gas, but this is preferably at approximately atmospheric pressure so as to reduce the range of travel of debris ejected from the target when subjected to the laser light focussed thereon. In known manner the target will normally be focussed within a chamber containing gas, but this is preferably at approximately atmospheric pressure so as to reduce the range of travel of debris ejected from the target when subjected to the laser light focussed thereon. Preferably also, means is provided for blowing a current of gas over the surface of the region